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Review Article

Polymer-Nanocomposite based Flame Retardant Functional Finishing for Sustainable Textile Coating

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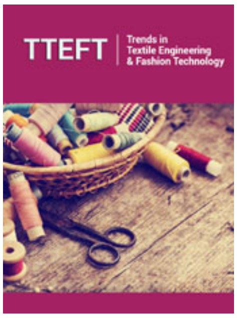
ISSN: 2578-0271



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Submission: June 17, 2024
Published: August 09, 2024

Volume 10 - Issue 2

How to cite this article: Sana Javaid* and Shafi Ur Rehman. Polymer-Nanocomposite based Flame Retardant Functional Finishing for Sustainable Textile Coating. Trends Textile Eng Fashion Technol. 10(2). TTEFT. 000734. 2024. DOI: 10.31031/TTEFT.2024.10.000734

Abstract

The textile industry is an important economic sector worldwide. Functional and smart textile with inherent multi-functional properties such as flame retardant is need of better living standards. Combustion and burning of textile material in homes, hospitals, industries etc., can cause sever danger to some once lives and property. Textile manufacturers are now focusing on the development of functional textile finishing and coating to meet the needs of consumers worldwide. Natural and synthetic textile fiber, including cotton, polyester, wool, jute etc., are susceptible towards combustion and burning. Functional polymers coating woven and nonwoven fabric provides hydrophobic, hydrophilic, antistatic, soil repellent, antifouling and flame-retardant textile finishing. This mini review focuses on the flame-retardant properties of polymeric nanocomposite for fire resistant woven and non-woven sustainable textile finishing.

Keywords: Flame retardant; Polymer-based textile; Nanoparticles; Coating

Introduction

Flame retardant polymeric formulation in textile treatment received much attention from scientists and researchers worldwide. Polymeric nano formulation including natural and synthetic polymers, having flame retardant functional group develops a fire protection layer on the surface to inhibit the combustion phenomena. Polymeric formulations can be coated on textile via conventional dipping and pad dry cure technique using volatile curing agent and crosslinker through wet finishing treatment. While advanced coating furnished through layer-by-layer and sol gel technology excluding the toxic chemicals and provide an inexpensive, ecofriendly approach for textile industry [1,2].

Natural and synthetic fiber such as cotton, jute, hemp, wool, bamboo, polyester and nylon have been considering an excellent clothing material but is highly responsive towards burning [3]. In addition to clothing and apparel, these synthetic and natural fiber material employed in many smart and functional textile including E-textile, stimuli responsive, shape memory, biomedical, sports and construction [4-6]. Thus, rendering this material as flame retardant is a key subject area for today's textile researchers.

Flame retardant materials including halogens, organo-phosphorus, nitrogen, metals nanoparticles (aluminum and magnesium, borax, antimony trioxide and molybdenum,) used commercially [7-10]. Moreover, these nanoparticles blended in composite and polymeric formulation employed in various coatings to delay the ignition or spread of fire [11,12]. Flame retardants interfere with the burning process either by self-extinguishing phenomena, char enhancing layer and bio inspiring. Halogenated flame retardant shows as gas phase mechanism in decomposing the heat producing radicals and form a blanket to serves as fire inhabiting layer on the surface of polymer [13]. The major drawbacks are the release of toxic gases and free radicles to hindered in sustainable environment. Non halogenated flame retardants including metal hydroxide, clay nanoparticles, and organo phosphorus compounds binds non-covalently to the polymer surface serves as promising candidate with non-toxic, ecofriendly and cost-effective treatment [14-16].

This review focuses on the development of flame-resistant textile coating followed by char enhancing, self-extinguishing and bio inspiring mechanisms. Polymeric formulation-based multifunctional finishing for cotton, polyester and wool via layer-by-layer and dip coating techniques are safe solutions to avoid the use of toxic crosslinkers. Thus, environmentally friendly approach of utilizing safe chemicals in textile finishing treatments are choice of textile experts. Reducing the emission of volatile gaseous substances and non-halogenated free radicles potentially maintaining the sustainable natural ecosystem.

Fire retardant functional groups and mechanism of action

Commercially available flame retardants and their mechanism of action are shown in Figure 1. Non-halogenated flame retardants including metal hydroxide such as aluminum hydroxide, magnesium hydroxide and inorganic fiber-based material are illustrated in fig 1 a while three mode of fire inhibition are illustrated in 1 b respectively [17-19]. They reduce the fire hazards of polymeric textile material in condensed phase and release non-flammable water molecules in facilitating the protective ceramic coating [20-22]. Silica-containing flame retardants improve the flame retardancy of polymers by accumulating low surface energy silicon dioxide ($SiO2$) aggregates in the condensed phase to form a protective layer, but their low efficiency is not suitable for practical industrial applications [23,24]. Phosphorus- containing flame retardants, such as inorganic red phosphorus and organic phosphorus- containing compounds, mainly work by interfering with active H• and •OH in the gas phase, thereby achieving high flame-retardant efficiency [25].

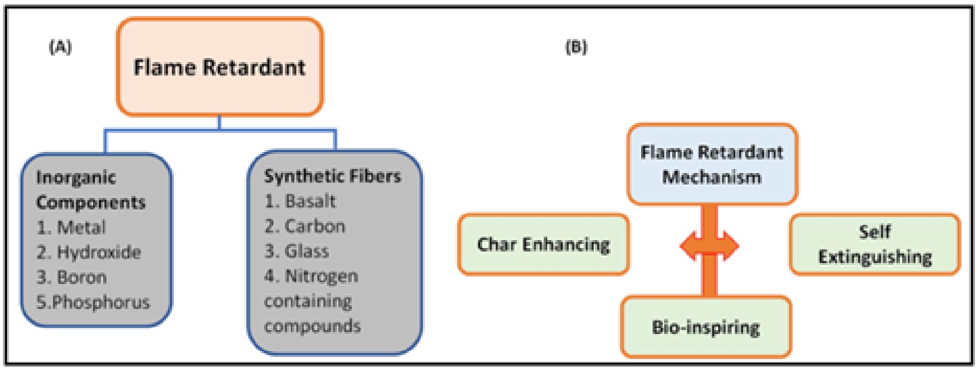

Figure 1: Fire retardant functional groups and mechanism of action.

Cotton, polyester, jute, wool all are polymeric materials and used extensively in clothing as well as functional and smart textile manufacturing [26,27]. Though highly combustible as cotton decomposes at temperature below 150 °C by desorbing water molecules and start endothermic, self-sustaining combustion process. Similarly, all woven and non-woven polymeric material burns via exothermic process release flammable and non-flammable gases and other byproducts [28].

Thus, to reduce the flammability issue in textile, inorganic based functional finishing applied including phosphorus, nitrogen containing functional groups, clay, magnesium oxide etc. Inorganic materials incorporated at the finishing stage or can be coated via sol-gel technique to provide durable, semi-durable and non-durable flame retardancy properties [29-32]. Silver doped titania nanoparticles using 3- (trihydroxysilyl)propyl methylphosphonate (TPMP) via a sol-gel technique was employed for multifunctional, antibacterial, anti-UV, and flame-retardant properties

in cellulosic fabric. The surface treatment of doped silver with phosphorus-based flame-retardant acts as intumescent flame retardant by forming char layer and inhibiting the further decomposition by burning [33]. However, durability in textile is affected by having intumescent flame-retardant finishes.

Nanoencapsulated flame retardant

Nanosized filler reinforced polymer composite based formulation is gaining widespread use. Polymeric formulations involve the use of non-toxic auxiliary agents, thermally and mechanically stable polymers, while multi-functional fibers and fillers to enhance the characteristics property of textile. The polymer nanoformulation can be easily coated via dipping, pad-dry-cure, and layer- by-layer surface treatment using an aqueous environment [2,34,35].

Nanoencapsulation of flame-retardant moiety inside the inorganic and organic polymer can cause release of functionality is another semi-durable flame-retardant functional finish for various substrates including textile, paints, and polymers [36]. Red phosphorus is an excellent material as an alternative to halogenated flame retardant. Phosphorus works as a dual functional flame retardant either gas phase by inhibiting the release of flammable radicles and condensed phase by forming char layer. Red phosphorus is encapsulated inside silica shell as sol-gel precursors for coated flame-retardant finishing. Homogeneous silica shell was recovered by using tetraethoxysilane (TEOS) in an aqueous solution. Moreover, the silica based inorganic coating on red phosphorus showed semi-permanent shielding toward flame and combustion. Self- extinguishing flame-retardant coating was characterized for morphology and thermal stability through SEM and TGA. However, the durability in sol-gel phenomena of surface treatment is yet to be studied in detail [37].

Polymer/ CNT based flame retardant

The flame-retardant properties of polymer/carbon nanotube composites have attracted attention worldwide. The non-combustible behavior of different types of polymer matrix reinforced carbon nanotube fillers is a new field in technical and smart textile having improved mechanical, thermal and flame-retardant properties. CNTs have hexagonal closed packed lattice and exhibit extraordinary mechanical strength and flexibility. CNTs are chemically inert and resistive to corrosion. Moreover, exhibit non-flammability thus incorporated as filler in polymer matrix composite, as non-combustible, ecofriendly and sustainable flame-retardant polymer composite in majority of structural and nonstructural applications [38-40]. Polymer matrix including epoxy, polystyrene, polyaniline, polypropylene and polyurethane reinforced CNTs are significant in enhancement of nonflammability of polymers. The fabricated polymer composites were investigated using limiting oxygen index measurements. CNTs based nanocoating on polymeric composite material can significantly enhance the flame retardancy without reducing the mechanical strength of woven and non-woven fabric [41].

Polymer composite based textile as an advanced engineering has been replacing the conventional textile material. CNTs reinforced polyurethane coating was furnished in a PU resin by employing commercially available phosphorus flame retardants. The reduced flammability of PU coating was achieved by single and double walled CNTs. CNTs showed intumescent flame-retardant ability by swelling and decreasing the density of surface layer after coating of combustible polymers. Thus, CNTs can provided reduce heating time and delayed ignition by insulating the material in a sealed coating [42].

Metal Oxide/ hydroxides base flame retardants

Many metals oxide provides multifunctional properties as self-cleaning, antimicrobial, anti-UV, flame retardant, hydrophobic, and electrically conductive in smart and functional textile. The flame retardancy of ZnO is based on the condensed phase mechanism through the thermal barrier effect. Zinc oxide as thermally stable can provide the insulation barrier on the surface of textile thus collapse the pathway of combustion by reducing the oxidant and fuel transfer [43]. ZnO nanoparticles are encapsulated inside the polymeric shell can be coated on cotton, jute, and sisal fiber by dip coating, and layer by layer dip coating technique to fabricated flame retardant and UV protective functional textile. Further the thermal stability of the coated fabric enhanced as compared to uncoated fabric [44,45].

Metal hydroxides also act as effective smoke suppressant and flame retardant by decomposition phenomena. The coated textile with metal hydroxide initiates graphitization, thus producing incombustible gases and preventing the damage due to heat. Besides metal oxide and metal hydroxides, layer double hydroxides LDH are a new class of flame retardant for polymeric and textile coating. LDH depicts condensed phase mechanism by establishing a heat-resistant barrier and catalyzed the charring phenomena [46,47]. Flame retardancy is affected by structure,

composition and internal anionic layers coated on the surface. Thus, LDH provides high flame retardancy with min loading of 20 weight percent in polymer matrix with improvised mechanical stability. LDH reinforced polymer matrix composites exhibited self-extinguishing flame retardancy with inherent flame-resistant phenomena [48,49].

Similarly, LDH reinforced nitrogen coating natural flame-retardant coating have been significantly work for fabricating functional textile. Natural plant derivatives can also enhance the flame retardancy of fabricated composite material by forming the carbonaceous slag material which act as barrier or film rendering the heat resistant from combustion. Various natural and synthetic organic functional groups can be incorporated with LDH/ polymeric composites for functional textile finishing with inherent flame resistance ability [50].

Conclusion

Today's textile industries focus on non-conventional structurally smart and efficient material for manufacturing multifunctional woven and non-woven textile and fiber substrate. This review focuses on the flame-retardant mechanism of polymer composite based functional textile coating. Polymer composite based encapsulated organic and inorganic functionalities provided an ecofriendly sustainable coating for functional textile finishing. Three modes of flame retardancy as intumescent, self-extinguishing and bio based by forming carbonaceous material to provide barrier properties are described. Metal oxides, metal hydroxides, LDH, phosphorus, and CNTs as non-halogenated flame retardants and thermally stable and released non-flame able gases. Textile finishing achieved by layer-by layer dip coating as compared to conventional dip coating and pad dry-cure technique is potentially safe and ecofriendly approach without using toxic cross linkers. Thus, flame retardant polymer composites are potentially non-conventional, and environmentally safe material for smart, and functional textile substrates.

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